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**(54) Epitaxial silicon layer and method to deposit such**

Epitaktische Siliziumschicht und Verfahren zu deren Abscheidung

Couche épitaxiale de silicium et méthode pour sa déposition

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(73) Proprietor: **International Business Machines  
Corporation**  
**Armonk, N.Y. 10504 (US)**

(72) Inventor: **Meyerson, Bernard S.**  
**Yorktown Heights, N.Y. 10598 (US)**

(74) Representative: **Schäfer, Wolfgang, Dipl.-Ing.**  
**IBM Deutschland**  
**Informationssysteme GmbH**  
**Patentwesen und Urheberrecht**  
**D-70548 Stuttgart (DE)**

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**EP-A- 0 259 759 DE-A- 2 719 464**  
**US-A- 4 716 445**

- **PATENT ABSTRACTS OF JAPAN vol. 12, no. 397 (E-672)21 October 1988 & JP-A-63 137 414 (NEC CORP.) 9 June 1988**
- **PATENT ABSTRACTS OF JAPAN vol. 12, no. 397 (E-672) 21 October 1988 ; & JP-A-63 137 414**

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## Description

The present invention is concerned with a n-type silicon layer which includes an n-type dopant and germanium wherein the germanium is present in an amount that does not necessarily result in a significant decrease in the band gap of the layer. In addition, the present invention is concerned with a method for epitaxially depositing an in-situ doped n-type silicon layer onto a substrate, and is particularly concerned with a low temperature, low pressure chemical vapor deposition method. The present invention is also concerned with deposited, in-situ doped n-type silicon layers obtained by the process of the present invention.

The current desire in the electronics industry to provide high performance integrated circuitry of reduced dimensions has created a tendency to employ lower processing temperatures. For instance, the dimensions of device layers deposited by silicon epitaxy at the more typical temperatures employed, for instance, temperatures greater than about 1000°C, are fixed at values greater than the diffusion length of dopants out of the substrate onto which the silicon is deposited. For instance, such dimensions are typically on the order of a micrometer or more. However, the production of thin epitaxial films of silicon having abrupt and arbitrary dopant profiles is vital in device and circuit fabrication, and particularly in applications such as scaled-down bipolar and CMOS VLSI circuits and processes.

Various attempts at achieving lower processing temperatures were not especially successful because of a number of problems that need to be overcome before reduced temperatures such as those below about 800°C could be used. For instance, at such reduced temperatures, the number of epitaxial defects can increase markedly. Also, at such relatively low temperatures, dopant atoms do not have sufficient mobility to find electrically active substitutional sites in the silicon lattice.

However, various ones of these problems have been overcome and the ability to employ relatively low temperatures of 800°C and less has been realized by employing ultrahigh vacuum as disclosed for instance by Meyerson, "Low-Temperature Silicon Epitaxy By Ultrahigh Vacuum/Chemical Vapor Deposition", Applied Physics Letters 48 (12), pp. 797-799, March 24, 1986, Meyerson, et al., "Low Temperature Silicon Epitaxy By Hot Wall Ultrahigh Vacuum/Low Pressure Chemical Vapor Deposition Techniques: Surface Optimization", Journal of the Electrochemical Society, Vol. 133, No. 6, June 1986 and Srinivasan, et al., "Current Status of Reduced Temperature Silicon Epitaxy By Chemical Vapor Deposition", Electrochemical Society, Soft Bound Proceeding Series, Pennington, New Jersey, 1985.

In addition, a particularly effective process employing low temperature and low pressure chemical vapor deposition of epitaxial silicon is disclosed in U.S. Patent applications Serial Nos. 906,854 filed September 12, 1986 and 342,630 filed April 9, 1989, disclosures of

which are incorporated herein by reference. Although this process is especially effective for producing quality epitaxial silicon layers, such could still stand improvement with respect to the amount and uniformity of the in-situ n-type dopants provided. In particular, the deposition of in-situ doped n-type epitaxial silicon films is especially difficult at the lower processing temperatures of about 800°C and less. This difficulty arises from the failure of the n-type dopants such as phosphorus and arsenic to bond substitutionally into the silicon lattice.

Moreover, additional complications arise from the time varying nature of phosphorus incorporation, where the quantity of phosphorus bound into the film in any coordination is a strong function of deposition time. This effect can be seen in Fig. 1, where a constant flow of phosphine into a 550°C ultrahigh vacuum/chemical vapor deposition reactor results in a continually increasing phosphorus content in the film. Furthermore, electrical analysis of these layers shows that the phosphorus is electrically inactive and therefore ineffective as a n-dopant.

Accordingly, it is a primary object of this invention to provide an improved technique for low temperature deposition of in-situ n-doped silicon.

It is another object of this invention to provide enhanced n-type doping in a silicon film deposited by ultrahigh vacuum chemical vapor deposition (UHVCVD).

It is another object of this invention to provide an improved low temperature technique for fabricating silicon devices containing at least one pn junction.

It is another object of this invention to provide structures including a silicon layer therein which are n-doped as deposited, without the need for additional steps such as annealing to make the dopants electrically active.

It is another object of this invention to provide improved silicon products containing n-type doping, by the methods of this invention.

It is another object of this invention to provide an UHVCVD process that allows in-situ n-type doping of deposited silicon films, over a wide range of doping levels.

It is still another object of this invention to provide a method for and device having abrupt n-type doping profiles.

It has been found in accordance with the present invention that n-type dopants can be incorporated into a silicon film as electrically active impurities at temperatures well below those which were previously believed necessary for such purpose. In particular, the present invention makes the fabrication of in-situ deposited pn and np symmetric junctions possible, which in turn allows the fabrication of any silicon based device. The present invention makes it possible to control the quantity of the n-type dopant to thereby provide dopant uniformity. Dopant uniformity is a critical requirement for the high quality devices presently being demanded in the electronics industry.

In particular, one aspect of the present invention is directed to a method for depositing an in-situ doped n-

type silicon layer onto a substrate. The method includes providing the substrate in a chemical vapor deposition reactor zone. The temperature in the chemical vapor deposition zone is about 800°C or less and the base pressure in the reactor zone is an ultrahigh vacuum that is less than the partial pressures of any contaminants present in the chemical vapor deposition zone.

A gas containing silicon is introduced into the reaction zone for the deposition of silicon on the substrate along with an n-type dopant-containing gas and a germanium-containing gas. The germanium-containing gas is present in an amount that is effective for enhancing the in-situ incorporation of the n-type dopant into the silicon layer as an electronically active dopant, whereby about 1 to about 35 atomic percent of germanium based upon the total of n-type dopant and germanium is produced in said silicon layer.

A further aspect of the present invention is concerned with products obtained by the above defined process, where such products are not obtainable with any other process at temperatures less than 750°C.

Furthermore, the present invention is concerned with a silicon layer, preferably epitaxial, that can be included in a complete NPN or PNP transistor, which layer includes an n-type dopant and germanium. The germanium is present in the silicon layer in the amount of about 1 to about 35 atomic percent based upon the total of n-type dopant and germanium.

Fig. 1 illustrates the effect of doping with phosphorus according to prior art ultrahigh vacuum/chemical vapor deposition reaction.

Fig. 2 illustrates the effect of employing germanium in combination with the n-type dopant pursuant to the present invention.

Fig. 3 is a cross-sectional view of a double epitaxial, double heterojunction PNP transistor illustrating a device made in accordance with the present invention.

It has been found pursuant to the present invention that the inclusion of relatively minor amounts of a germanium-containing gas in the input gas in an ultrahigh vacuum/chemical vapor deposition UHVCVD reaction for forming an in-situ doped n-type (epitaxial) silicon layer results in the incorporation of stable and defined amounts of electrically active n-type dopant in the silicon film.

The surprising effect achieved by the present invention is demonstrated by a comparison of Fig. 1 with Fig. 2. In particular, Fig. 1 represents prior art whereby a constant flow of phosphine into a 550°C ultrahigh vacuum/chemical vapor deposition reactor results in a continually increasing phosphorus content in the silicon film. Electrical analysis of these layers shows that the phosphorus is electrically inactive.

Fig. 2 and that portion of Fig. 2 identified as portion A substantially repeats the above process for the first 150 nanometers of film growth whereby the same phenomena occur as described for Fig. 1. On the other hand, that portion of Fig. 2 identified as portion B demonstrates the effect when a relatively small amount (i.e. - about 7 atomic percent) of a germanium-containing gas (such as germane) is included along with the phosphine in the input gas. The results demonstrate that the phosphorus content is increased to a stable value where it remains. Moreover, electrical analysis of this layer establishes that the phosphorus is fully activated.

As is apparent from portion B of Fig. 2, the onset of n-type dopant incorporation is extremely abrupt when the Ge-containing gas is introduced into the reaction zone. Even though the phosphine gas has been continually introduced, the incorporation of P as a fully electrically active dopant species does not occur, especially at high doping levels in excess of  $10^{19}$  atoms/cm<sup>3</sup> until the Ge-containing gas is introduced into the reaction zone. At this time, the phosphorus dopant is incorporated in the proper substitutional sites in the silicon lattice as fully electrically active dopants.

For the low temperature (less than 750°C) deposition of silicon, gaseous sources are required which will pyrolyze at low temperatures. Typically, these will be gaseous sources containing hydrogen, such as silane (SiH<sub>4</sub>). As a by-product of the decomposition of the growth species, H atoms can appear on the growth interface. Additionally, phosphorus acts as a poison for growth in that the P can tend to form clusters of P<sub>2</sub> on the silicon growth surface. When the phosphorus is present as clusters, electrically active dopants will not be produced in the proper sites in the silicon lattice. Also, these phosphorus clusters can hold H atoms on a silicon surface, as the P-H bonds are very strong. This tends to further inhibit both silicon growth and incorporation of fully electrically active n- dopant species.

It is believed that the presence of Ge aids in the desorption of H atoms from the growing surface, thereby allowing the n-dopant to go directly to a substitutional site in the lattice where it is fully electrically active as a dopant. However, the presence of Ge may still be helpful in the incorporation of n-dopant species even if hydrogen atoms are not present on the silicon surface, by enhancing the solubility of the n- dopant into the silicon at low temperatures. The net effect is that the presence of Ge increases the effective solubility of these n-dopants into silicon.

As noted, the presence of Ge is particularly important for low temperature n-doping of silicon, since it allows the in-situ incorporation of fully electrically active dopants. It also leads to an abrupt turn-on of doping activity thereby leading to the formation of very sharp pn junctions. The use of Ge in this manner is particularly applicable to chemical vapor deposition processes, but is also applicable to other processes utilizing gaseous sources. For example, vapor phase epitaxy using chem-

ical vapor deposition or molecular beam epitaxy (MBE) with gas sources are examples of processes that can be used.

The use of a germanium-containing gas to achieve the results obtained by the present invention was not at all apparent from any prior art. In fact, to use germanium as a doping enhancement in heavily doped n-type material is contrary to prior uses of germanium whereby such is employed in the fabrication of bipolar transistor bases whose band gap is to be decreased. Although a reduced band gap is desired for the base region, most heavily doped n-type material is employed in the emitter of these devices (NPN), where an increase in band gap is desired. However, the amounts of the germanium used in the present invention are small enough that the primary band gap reduction mechanism is the presence of the n-type dopants at relatively high levels instead of the effect of the germanium. Accordingly, the germanium is present in this invention in an amount that is both effective for enhancing the in-situ incorporation of the n-type dopant into the silicon layer as an electronically active dopant, but less than that which would result in a significant decrease (e.g. - a decrease more than 100 meV) in the band gap in the device obtained. According to preferred aspects of the present invention, in a NPN transistor, about 1 to about 35 atomic percent of germanium is introduced in the case of a base and about 1 to about 20 atomic percent of germanium is introduced in the case of an emitter, and most preferably about 5 to about 20 atomic percent in the case of a base and about 2 to about 15 atomic percent in the case of an emitter.

The germanium-containing gas employed can be any germanium gas such as the germanium hydrides and preferably germane (i.e. - germanium tetrahydride) Another suitable germanium-containing gas is germanium tetrachloride.

The n-type dopants that can be employed are well known in the prior art and need not be described herein in any great detail. However, the preferred n-type dopants are phosphorus, arsenic, and antimony. The phosphorus-containing gas employed can be phosphine or  $\text{POCl}_3$  with phosphine being most preferred due to its decomposition at low temperatures. Suitable arsenic-containing gases include arsine or  $\text{AsCl}_3$ . A suitable antimony gas is  $\text{SbH}_3$ .

The level of the n-type dopant in the silicon layer can vary over a wide range but generally is about  $1 \times 10^{14}$  to about  $1 \times 10^{20}$  atoms per  $\text{cm}^3$ . The doping level is determined based on the desired device characteristics.

The silicon source gas for the deposition of silicon is not especially critical and can be any of the silicon source gases known in the art such as silane, higher order silanes including disilane ( $\text{Si}_2\text{H}_6$ ), and chlorosilanes such as  $\text{SiCl}_4$ ,  $\text{SiH}_2\text{Cl}_2$ ,  $\text{SiHCl}_3$ , and  $\text{SiH}_3\text{Cl}$ .

It is recognized that heterojunction bipolar transistors (HBT) have been fabricated in the art in both npn and pnp form. In pnp HBTs, a silicon base region is used in which Ge is present. Ge is used therein to decrease

as much as possible the band gap of the base region in order to enhance operation of the transistors. However, those devices are generally made in a process wherein thermal diffusion, ion implantation or high growth temperatures are used to place the n-dopant species and Ge in the base region. High temperature steps, such as thermal diffusion and high temperature annealing or high growth temperatures are used to electrically activate the dopant species. Thus, in prior implanted pnp HBT's, the Ge is not introduced at the same time the n-type dopant is introduced in the base layer, in further distinction with the present invention where Ge and the n-dopant are present at the same time in the reaction zone. In deposited devices Ge and the dopant Sb are co-deposited at high growth temperatures to activate the dopant, Sb. The Ge used in the present invention need not be used to significantly alter the band gap of the n-type silicon layer, but instead to enable full electrically active incorporation of n-type dopants in-situ. This creates very abrupt dopant profiles, and therefore enables the fabrication of very narrow structures.

Accordingly, in the practice of the present invention, the product obtained by the inventive process described herein is unique in its properties and can be used to provide advantageous devices, such as transistors. In bipolar transistors, it is desirable to have highly doped emitter regions where the band gap of the emitter is not appreciably reduced. Further, the emitter need not be single crystalline, since the strain produced in a single crystalline material can reduce the band gap of the emitter. By the use of this invention, n-type emitter layers can be produced with the desired doping levels and band gaps.

In heterojunction bipolar transistors using Si-Ge layers, it has been the case in the prior art that high temperatures have been required to incorporate sufficient quantities of electrically active dopants. However, high temperatures affect Si-Ge layers, causing them to relax by forming defects (dislocations) which in turn adversely affect device operation. The present invention avoids this problem by enhancing the incorporation of fully electrically active n-dopants at low temperatures without leading to defect formation.

The preferred apparatus as well as process parameters for carrying out the improved process of the present invention are those employed in U.S. Patent applications Serial Nos. 906,854 and 07/342,630 disclosures of which are incorporated herein by reference. For instance, the apparatus employed is preferably a hot wall, isothermal chemical vapor deposition apparatus of the type shown in said U.S. applications Serial Nos. 906,854 and 342,630. Device quality epitaxial silicon layers can be deposited with this apparatus.

The deposition temperatures employed are about  $300^\circ\text{C}$  to about  $800^\circ\text{C}$  with the preferred temperatures being about  $450^\circ\text{C}$  to about  $750^\circ\text{C}$  and the most preferred being about  $500^\circ\text{C}$  to about  $550^\circ\text{C}$ .

The base pressure employed is less than about  $10^{-8}$  Torr and preferably less than about  $1.3 \times 10^{-6}$  Pa ( $1 \times 10^{-8}$

Torr). The apparatus employed is a flow system in which the source gases (silicon source gas, n-type dopant source gas and germanium source gas) are injected at one end and high- speed pumps operate at the other end, there being a load lock to eliminate contamination upon loading of the substrates prior to deposition. The system typically operates in a molecular flow regime where the total operating pressure of the source gases is less than several tens of Pascal (several hundred mTorr) during deposition. While the preferred total operating pressure of the source gases during deposition is about 1.3 Pa to about  $1.3 \cdot 10^{-2}$  Pa (about  $10^{-2}$  to about  $10^{-4}$  Torr), source gas pressures up to several tens of Pascal (several hundred millitorr) may be possible when very low growth temperatures of less than about 500°C are used.

Accordingly, the present invention enhances the incorporation of n-type dopants into epitaxial silicon and provides for such to be incorporated as electronically active species without any additional steps, such as high temperature annealing and high temperature deposition as required in prior art techniques.

Fig. 3 is a cross-sectional illustration of a double epitaxial double heterojunction PNP transistor in which both the base and emitter regions are formed by low temperature epitaxy using the aforementioned UHV/CVD process. A two-step epitaxial process is used wherein low temperature epitaxy is used to form the base region and another low temperature epitaxy step is used to form the emitter region.

In the formation of the transistor of Fig. 3, the base region is heavily doped (phosphorus  $10^{19} \text{cm}^{-3}$ ) SiGe film. Advantage is taken of the epitaxial base technology because the thermal cycles following the base deposition, which can cause dopant diffusion and relaxation of highly strained layers, are eliminated. As will be seen, the insulating layers are formed by plasma enhanced CVD and the emitter region is formed by low temperature epitaxy, thereby limiting the temperature after base deposition to 550°C and lower.

The transistor 10 is a non-self aligned structure that is used to illustrate low temperature processing technology in accordance with the present invention. Transistor 10 includes an extrinsic base polysilicon region 12 and an ion implanted collector region 14. Emitter 16 is also a low temperature epitaxial layer. A field oxide layer 18 overlies the p-type substrate 20. Plasma enhanced CVD is used to produce oxide layers 22 and a nitride layer 24.

Reference is made to D.L. Hareme, et al. IEDM, pp. 889- 890 (1988) and G.L. Patton, et al., VLSI Symposium, pp. 95-96 (1989) for discussions of a non-self aligned structure and method. The extrinsic base polysilicon 12 is patterned and etched to form a second, smaller window inside the opening in the field oxide 18 (the non-self aligned opening), through which boron is implanted and annealed to increase the collector doping concentration in ion implanted collector 14. The intrinsic base 26 is grown by UHV/CVD low temperature epitaxy

at 550°C, as detailed by B.S. Meyerson, et al., Appl. Phys. Lett., Vol. 50, p. 113 (1987).

Thermal quality oxide layers 22 were deposited at 350°C using plasma enhanced CVD. An emitter opening was then defined and etched within the non-self aligned opening and the single crystal emitter 16 was deposited by UHV/CVD at 550°C.

As an alternative structure a NPN transistor can be made using the same process as that used to make the transistor of Fig. 3, the only difference being that the conductivity types are interchanged.

As a consequence of the present invention, enhanced N-type doping is obtained, which allows wafer scale integration to be achieved. Since the uniformity of N-type doping concentration is extremely uniform across the wafer, integrated circuits can be made using all NPN or PNP devices, as well as with circuits including complementary devices. For example, a silicon wafer including a large number of integrated circuit chips can be processed at one time with excellent uniformity of device properties across the wafer. In particular, integrated silicon heterojunction bipolar transistors can be wafer scale integrated.

The following non-limiting example is presented to further illustrate the present invention.

#### EXAMPLE

An n-type epitaxial silicon layer is deposited onto a substrate by introducing  $\text{SiH}_4$  at about 20 sccm (standard  $\text{cm}^3$  per minute),  $\text{GeH}_4$  at about 0.2 sccm, and 100 ppm  $\text{PH}_3$  in He at about 4 sccm at a temperature of about 550°C and total growth pressure of about 0.16 Pa (1.4 mTorr). The results obtained are illustrated in portion B of Fig. 2. The layer illustrated in portion B showed an n-type carrier density of about  $4 \times 10^{19}$  electrons/ $\text{cm}^3$  establishing full electrical activation of the phosphorus dopant present.

While the invention has been shown with respect to the embodiments described herein, it will be apparent to those of skill in the art that variations can be made. For example, the exact operating parameters of the UHV/CVD process described in the cited co-pending applications can be varied, and the silicon layer need not be epitaxial, although epitaxial deposition is often preferred. While thermal CVD systems are described in those cited co-pending applications, other types of excitation (plasma, etc.) will be recognized by those of skill in vapor deposition techniques as being suitable. Further, the degree of epitaxy is known to vary and need not be 100% lattice matching. Still further, the use of these silicon layers, having enhanced n-type doping, is not limited to any particular device, but can be used in bipolar transistors, diodes, Schottky barrier devices, FET's, etc.

**Claims**

1. A method for depositing an in-situ doped n-type silicon layer onto a substrate which comprises

providing the substrate in a chemical vapor deposition reaction zone wherein the temperature in said reaction zone is about 800°C or less and the base pressure in said zone is an ultrahigh vacuum; and

introducing a gas containing silicon into said reaction zone for the deposition of silicon on said substrate, and simultaneously therewith introducing an n dopant-containing gas and a germanium-containing gas in an amount effective for enhancing the in-situ incorporation of said n-type dopant into said silicon layer as an electronically active dopant whereby about 1 to about 35 atomic percent of germanium based upon the total of the n-type dopant and germanium is produced in said silicon layer.

2. The method of claim 1 wherein said temperature is in the range of about 300°C to about 800°C.

3. The method of claim 1 or 2 wherein said base pressure is less than about  $1.3 \cdot 10^{-6}$  Pa ( $10^{-8}$  torr).

4. The method of anyone of the claims 1 to 3 wherein the total operating pressure during deposition is in the range of about 1.3 Pa to about  $1.3 \cdot 10^{-2}$  Pa (about  $10^{-2}$  to about  $10^{-4}$  torr).

5. The method of anyone of the claims 1 to 4 wherein said n-type dopant containing gas is a gas containing phosphorus or arsenic, antimony or mixtures thereof.

6. The method of anyone of the claims 1 to 5 wherein said n-type dopant containing gas is phosphine or  $\text{POCl}_3$  or  $\text{PCl}_3$ .

7. The method of anyone of the claims 1 to 6 wherein said germanium-containing gas is a germanium hydride, especially germanium tetrahydride.

8. The method of anyone of the claims 1 to 7 wherein said gas-containing silicon is selected from the group of silane, higher order silanes, chlorosilanes, and mixtures thereof.

9. A transistor structure including a P-N junction, and containing a silicon layer wherein said layer contains an n-type dopant and germanium in an amount of about 1 to about 35 atomic percent based upon the total of the n-type dopant and germanium.

10. The transistor structure of claim 10 including at least one emitter-base p-n junction therein, said structure comprising:

a silicon base layer having p-type conductivity, and

a silicon emitter layer having n-type conductivity, said silicon emitter layer containing Ge in an amount less than that which would decrease the band gap of said silicon emitter layer by an amount in excess of about 100 meV.

11. The structure of claim 10, where said Ge is present in said silicon emitter layer in an amount of about 1-35 atomic percent based upon the total of n-type dopant and germanium.

12. The structure of claim 11, where said silicon emitter layer is an epitaxial layer.

13. The transistor structure of anyone of the claims 9 to 12 wherein said emitter contains Ge and is n-type doped to a level greater than about  $10^{19}$  carriers/cm<sup>3</sup>.

**Patentansprüche**

1. Ein Verfahren zum Abscheiden einer vor Ort dotierten Siliziumschicht von n-Typ auf einem Substrat, das umfaßt

das Verbringen des Substrats in eine chemische Aufdampf-Reaktionszone, wobei die Temperatur in der chemischen Reaktionszone etwa 800°C oder weniger beträgt, und der Basisdruck in dieser Zone ein ultrahohes Vakuum ist; und

Einführen eines siliziumhaltigen Gases in die Reaktionszone zum Abscheiden des Siliziums auf dem Substrat und gleichzeitig damit Einführen eines n-Typ-Dotierungsmittel-enthaltenden Gases und eines Germanium-enthaltenden Gases in einer Menge, die wirksam ist zum Steigern des Einbaus des Dotierungsmittels vom n-Typ in die Siliziumschicht vor Ort als elektronisch aktives Dotierungsmittel, wobei etwa 1 bis etwa 35 Atomprozent Germanium gerechnet auf den Gesamtbetrag des n-Typ-Dotierungsmittels und des Germaniums in dieser Siliziumschicht erzeugt wird.

2. Das Verfahren gemäß Anspruch 1, wobei die Temperatur im Bereich von etwa 300°C bis etwa 800°C liegt.

3. Das Verfahren gemäß Anspruch 1 oder 2, wobei der Basisdruck weniger als etwa  $1,3 \cdot 10^{-6}$  Pa (etwa  $10^{-8}$  Torr) beträgt.
4. Das Verfahren gemäß einem beliebigen der Ansprüche 1 bis 3, wobei der Gesamtbetriebsdruck beim Abscheiden im Bereich von etwa 1,3 Pa bis etwa  $1,3 \cdot 10^{-2}$  Pa (etwa  $10^{-2}$  bis etwa  $10^{-4}$  Torr) liegt.
5. Das Verfahren gemäß einem beliebigen der Ansprüche 1 bis 4, bei dem das das n-Typ-Dotierungsmittel-enthaltende Gas ein Gas ist, das Phosphor oder Arsen, Antimon oder Gemische aus diesen enthält.
6. Das Verfahren gemäß einem beliebigen der Ansprüche 1 bis 5, bei dem das das n-Typ-Dotierungsmittel-enthaltende Gas Phosphin oder  $\text{POCl}_3$  oder  $\text{PCl}_3$  ist.
7. Das Verfahren gemäß einem beliebigen der Ansprüche 1 bis 6, bei dem das Germanium-enthaltende Gas ein Germaniumhydrid, insbesondere Germaniumtetrahydrid ist.
8. Das Verfahren gemäß einem beliebigen der Ansprüche 1 bis 7, bei dem das siliziumhaltige Gas aus der Gruppe Silan, Silane höherer Ordnung, Chlorsilane und deren Gemische ausgewählt wird.
9. Eine Transistorstruktur mit einem P-N-Übergang, und enthaltend eine Siliziumschicht, wobei diese Schicht ein n-Typ-Dotierungsmittel und Germanium in einer Menge von etwa 1 bis etwa 35 Atomprozent enthält, gerechnet auf die Gesamtmenge des n-Typ-Dotierungsmittels und des Germaniums.
10. Die Transistorstruktur gemäß Anspruch 10, einschließlich wenigstens eines Emitter-Basis-p-n-Übergangs, wobei diese Struktur aufweist:
 

Eine Silizium-Basissschicht mit einer p-Typ-Durchlässigkeit; und

eine Silizium-Emitterschicht mit einer n-Typ-Durchlässigkeit, wobei die Silizium-Emitterschicht Ge in einer Menge enthält, die kleiner ist, als diejenige, die den Energiebandabstand der Silizium-Emitterschicht um einen Betrag von über etwa 100 meV verringern würde.
11. Die Struktur gemäß Anspruch 10, in der Ge in der Silizium-Emitterschicht in einer Menge von etwa 1 - 35 Atomprozent gerechnet auf die Gesamtmenge des n-Typ-Dotierungsmittels und des Germaniums enthalten ist.
12. Die Struktur gemäß Anspruch 11, in der die Sili-

zium-Emitterschicht eine Epitaxialschicht ist.

13. Die Transistorstruktur gemäß einem beliebigen der Ansprüche 9 bis 12, in dem der Emitter Ge enthält und mit Dotierungsmittel vom n-Typ auf eine Höhe über etwa  $10^{19}$  Träger/cm<sup>3</sup> dotiert ist.

#### Revendications

1. Procédé pour déposer une couche de silicium du type N dopée in situ sur un substrat, comprenant les étapes consistant à :

placer le substrat dans une zone de réaction de dépôt chimique en phase vapeur, la température dans ladite zone de réaction étant d'environ 800°C ou moins et la pression de base dans ladite zone étant un vide très poussé ; et

introduire un gaz contenant du silicium pour le dépôt de silicium sur ledit substrat, et introduire simultanément un gaz contenant des impuretés du type N et un gaz contenant du germanium en une quantité efficace pour stimuler l'incorporation in situ des dites impuretés du type N dans ladite couche de silicium sous la forme d'impuretés électroniquement actives, entre environ 1 et 35 pour-cent atomique de germanium, sur la base de la quantité totale d'impuretés du type N et de germanium, étant ainsi produit dans ladite couche de silicium.

2. Procédé selon la revendication 1, où la température est comprise entre environ 300°C et environ 800°C.

3. Procédé selon la revendication 1 ou 2, où ladite pression de base est inférieure à environ  $1,3 \cdot 10^{-6}$  Pa ( $10^{-8}$  torr).

4. Procédé selon l'une quelconque des revendications 1 à 3, où la pression de service totale au cours du dépôt est comprise entre environ 1,3 Pa et environ  $1,3 \cdot 10^{-2}$  Pa (environ  $10^{-2}$  et  $10^{-4}$  torr).

5. Procédé selon l'une quelconque des revendications 1 à 4, où ledit gaz contenant des impuretés du type N est un gaz contenant du phosphore, de l'arsenic, de l'antimoine ou des mélanges de ceux-ci.

6. Procédé selon l'une quelconque des revendications 1 à 5, où ledit gaz contenant des impuretés du type N est de la phosphine, du  $\text{POCl}_3$  ou du  $\text{PCl}_3$ .

7. Procédé selon l'une quelconque des revendications 1 à 6, où ledit gaz contenant du germanium est un hydruure de germanium, et plus spécialement du tétrahydruure de germanium.

8. Procédé selon l'une quelconque des revendications 1 à 7, où ledit gaz contenant du silicium est soit du silane, un silane d'ordre supérieur, un chlorosilane ou un mélange de ceux-ci. 5
9. Structure de transistor comprenant une jonction PN et contenant une couche de silicium, où ladite couche contient des impuretés du type N et du germanium dans une quantité comprise entre environ 1 et 35 pour-cent atomique sur la base de la quantité totale d'impuretés du type N et de germanium. 10
10. Structure de transistor selon la revendication 10 incluant au moins une jonction émetteur-base de type PN, ladite structure comprenant : 15
- une couche de base en silicium ayant une conductivité du type P, et
- une couche d'émetteur en silicium ayant une conductivité du type N, ladite couche d'émetteur en silicium contenant du Ge en une quantité inférieure à celle qui réduirait la bande interdite de ladite couche d'émetteur en silicium dans une proportion excédant environ 100 meV. 20 25
11. Structure selon la revendication 10, où ledit Ge est présente dans ladite couche d'émetteur en silicium dans une quantité comprise entre environ 1 et 35 pour-cent atomique sur la base de la quantité totale d'impuretés du type N et de germanium. 30
12. Structure selon la revendication 11, où ladite couche d'émetteur en silicium est une couche épitaxiée. 35
13. Structure de transistor selon l'une quelconque des revendications 9 à 12, où ledit émetteur contient du Ge et est dopé de type N à un niveau supérieur à environ  $10^{19}$  porteurs/cm<sup>3</sup>. 40

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FIG. 1

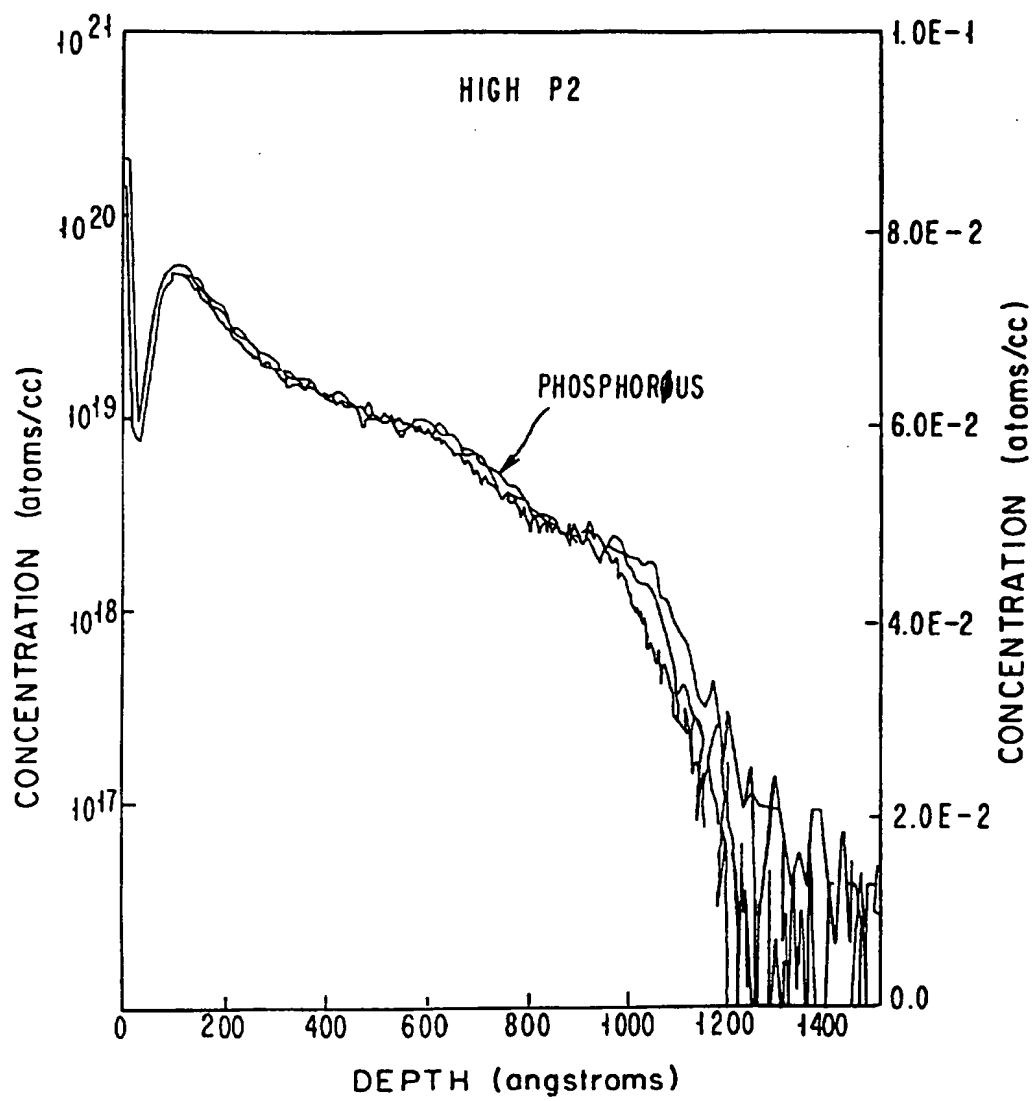


FIG. 2

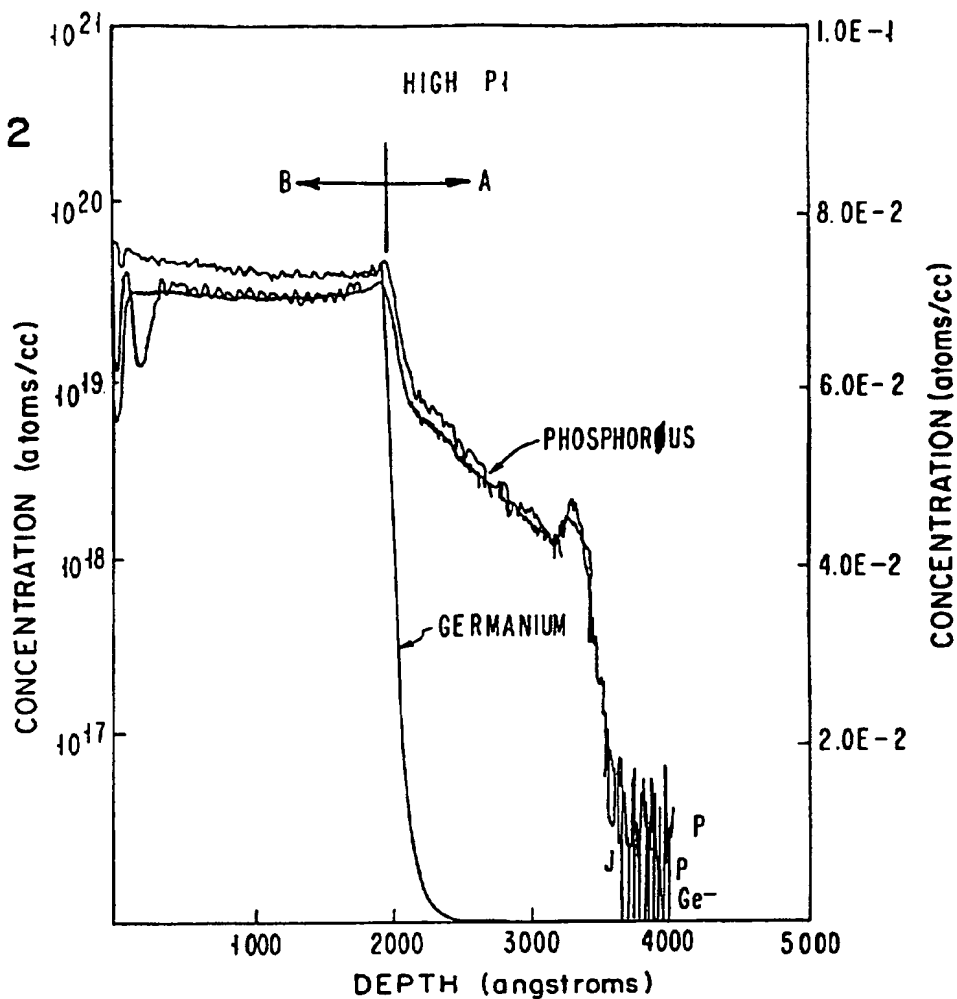


FIG. 3

